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Advances in CAD/CAM and Robotics: NRC Contributions

Commentary and Bibliography

J.H.C. Scrimgeour and F. Vernadat

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ABSTRACT

Work on CAD/CAM, robotics, and computer vision has been in progress at the National Research Council of Canada (NRC) at an increasing rate since 1980. More than fifty persons are involved in that activity in various Engineering Divisions of NRC.

This report presents highlights of more than 30 papers produced by NRC researchers and illustrates the various research and development efforts performed at NRC in the area of CAD/CAM and robotics over the last four years. Original contributions have been made in the fields of Robotics, multiprocessor architectures for realtime industrial computing, 3-D image acquisition and processing, CAD/CAM databases, CIM in the plastics industry, job shop scheduling and modelling, flexible manufacturing control, and CAD in building research. A bibliographical list at the end of the report provides a complete list of the papers published by NRC researchers and gives an overview of the global effort produced by NRC in the area of CAD/CAM and robotics.

RÉSUMÉ

Les travaux entrepris par le Conseil national de recherches du Canada (CNRC) dans les domaines de la CAO/FAO, de la robotique et de la vision par ordinateur ne cessent de se multiplier depuis 1980. Plus de 50 personnes issues des diverses divisions de génie du CNRC travaillent dans ces secteurs à l'heure actuelle.

Le présent rapport présente des résumés de plus de 30 articles publiés par les chercheurs du CNRC et reflète les divers travaux de recherche et développement réalisés par le CNRC en CAO/ FAO et en robotique au cours des quatre dernières années. Les travaux des chercheurs du CNRC ont produit des résultats nouveaux dans les secteurs de la robotique, des architectures de multiprocesseurs pour l'informatique industrielle en temps réel, de l'acquisition et du traitement d'images tridimensionnelles, des bases de données en CAO/FAO, de la fabrication intégrée par ordinateur (FIO) dans l'industrie des plactiques, de la modélisation et de l'établissement du calendrier des travaux réalisés à façon, de la gestion flexible des procédés de fabrication et de la CAO dans le domaine de la recherche en bâtiment. La liste bibliographique à la fin du rapport décrit tous les articles publiés par les chercheurs du CNRC et donne une vue d'ensemble des activités du CNRC dans les secteurs de la CFAO et de la robotique.

PREFACE

In its broad definition or meaning, Computer Aided Design and Computer Aided Manufacturing (CAD/CAM) includes robotics as one of its elements and is essentially synonymous with the alternate term, Computer Integrated Manufacturing (CIM). These terms do not denote a single technology, but in reality they refer to a group or set of system-related technologies. Especially when viewed collectively, these are seen to be transformative technologies. Transformative technologies are those with the ability to completely change the way in which things are done. They can influence the entire economic structure and well-being of nations as well as affecting individual companies in business and industry.

The purpose of this publication is to communicate the contributions to this field over the past five years which have their origins at the National Research Council of Canada. This work has involved the effort of more than fifty persons working in various engineering divisions of NRC (Division of Building Research (now the Institute for Research in Construction), Division of Electrical Engineering, Industrial Materials Research Institute, Institute for Marine Dynamics, Division of Mechanical Engineering, National Aeronautical Establishment).

Original contributions has been done in the fields of robotics, multiprocessor architectures for realtime industrial computing, 3-D image acquisition and processing, CAD/CAM databases, CIM in the plastics industry, job shop scheduling and modelling, flexible manufacturing control, and CAD in civil engineering. This report is unable to review all the work performed at NRC in the area covered by its title and some interesting papers have not been included. The interested reader will, however, find an exhaustive list of references on these topics at the end of the publication. Among these references, we suggest that, in addition to Burtnyk et al. (1984) the reader should consult the publication of the NRC CAD/CAM Interest Group (1986) which lists the various projects under development at NRC in the area of CAD/CAM and robotics. A short description is presented for each project and phone numbers of contact persons are indicated.

The editors hope that the highlights of each paper presented in this report will not only give a useful, interpretive overview, but will also encourage readers to proceed to a full study of the individual papers of interest to them. These papers are reproduced in a companion publication to this one, ERB-1003. ERB-1003 is available free-of-charge, while quantities last, from Editorial Office, Room 301, Division of Electrical Engineering, National Research Council of Canada, Ottawa, Ontario, Canada K1A 0R8

COMMENTARY

1. INTRODUCTORY READING AND BACKGROUND

1.1 N. Burtnyk, J. Scrimgeour, and V. Thomson. RESEARCH AND DEVELOPMENT AT NRC RELATED TO CAD/CAM AND ROBOTICS. Proceedings of the 3rd Canadian CAD/CAM and Robotics Conference, Toronto, Ont. 1984. pp. 3.7-3.17

The first paper in this series, by Burtnyk, Thomson, and Scrimgeour, presents an overview of CAD/CAM and robotics activities at NRC, essentially over the time period 1980-1984, and therefore serves as a more detailed introduction to the papers which follow. The work of many divisions is described, including the adaptive manufacturing cell in the Division of Mechanical Engineering, multiprocessor and sensor-based work in the Division of Electrical Engineering, the machine vision and speech analysis work for space applications in the National Aeronautical Establishment, database development in the Division of Building Research, plus work on CAD for the injection molding of plastic parts and robot welding in the Industrial Materials Research Institute.

Special mention is made in this paper of the Institute for Manufacturing Technology, then proposed and planned as a focal point for applied R&D and technology transfer to industry in CAD/CAM, robotics, sensors, integrated manufacturing, and artificial intelligence. Support, however, for the establishment of this institute was later discontinued by government in the fall of 1984. The remaining papers contained in this collection therefore arise from continued work in other divisions of NRC.

2. COMPUTER-INTEGRATED MANUFACTURING (CIM)

2.1 V. Thomson and U. Graefe. CIM - A MANUFACTURING PARADIGM. Proceedings of the 5th Canadian CAD/CAM and Robotics Conference, Toronto, Ont. 1985. SME Paper MS86-722.

In this paper myths about CIM and CIM concepts are discussed, management issues for CIM are presented, and the role of computers is emphasized. CIM is presented as a new manufacturing paradigm which promotes the integration of manufacturing functions as opposed to previous paradigms based on division of labor into areas of specialization.

2.2 F. Vernadat. KEY TECHNOLOGIES FOR SUCCESSFUL MANUFACTURING INTEGRATION (CIM). Proceedings of the CIMTECH Conference, Boston, MA. 1986.

In this paper by Vernadat, key technologies to be considered for successful manufacturing integration are discussed. In addition to the

definition of a company's strategic plan, the seven key technologies are Group Technology (GT), structured plant design and analysis methodologies, computer control system architectures, computer network technology, manufacturing communications protocols (such as MAP), database technology, and graphics data exchange standards (such as IGES or STEP).

3. CAD/CAM AND CIM DATABASES

Four papers in this section deal with the issue of CAD/CAM and CIM databases.

3.1 F. Vernadat. COMPUTER-INTEGRATED MANUFACTURING: ON THE DATABASE ASPECT. Proceedings of the 3rd Canadian CAD/CAM and Robotics Conference, Toronto, Ont. 1984. pp. 6.1-6.7

This paper describes the problem in its entirety by discussing the role of databases in the CIM concept, the nature of engineering information, and the physical versus the logical levels of CIM databases. The paper describes a general CIM database architecture and introduces the concept of Engineering Information Systems (EIS).

3.2 F. Vernadat. A CONCEPTUAL SCHEMA FOR A CIM DATABASE. Autofact 6 Conference Proceedings, Anaheim, CA. 1984

This paper concerns the possible data structure for a CIM database. A complete conceptual schema for a relational database is developed (with entity and relationship names and attributes) to support CAD, MRP, CAPP, CAM, QA/QC, and various production planning and control functions of a discrete manufacturing company.

3.3 F. Vernadat and W.H. Henneker. CAD/CAM DATABASES AT NRC: FROM MANUFACTURING CELL DATABASE SYSTEMS TO ENGINEERING INFORMATION SYSTEMS. Proceedings of COMPINT '85, Montreal, P.Q. 1985. pp. 441-446

This paper by Vernadat and Henneker is concerned with the physical level of CAD/CAM databases. It presents DBS/R, a relational database manager developed at NRC for automated manufacturing and nonconventional database applications.

3.4 A. DiLeva and F. Vernadat. INFORMATION ANALYSIS AND MODELLING OF PRODUCTION SYSTEMS. Proceedings of the 3rd International Conference on Advances in Production Management Systems (APMS 87), Winnipeg, Man. 1987

The fourth and final paper of this section on CAD/CAM and CIM databases is devoted to the important issue of conceptual and logical design of production databases, i.e., developing the data schema of a database for a given industrial application. The paper presents the M* methodology developed at NRC for information analysis and modelling of production systems.

4. CIM FOR DISCRETE MANUFACTURING

These four papers deal with the topic of CIM for discrete manufacturing.

4.1 V. Thomson and J. Neelamkavil. THE DEVELOPMENT OF A GENERIC JOB SHOP SCHEDULER AND SHOP MODELLER. Proceedings of the 4th Canadian CAD/CAM and Robotics Conference, Toronto, Ont. 1985

This paper presents the development of a generic job shop scheduler and shop modeller for medium and short term manufacturing planning of shop orders for small- to medium-sized industries. The package, now called FAMS, was developed by ICAM Technologies Corporation (Montreal) in collaboration with NRC. This paper discusses the scheduling part of the system.

4.2 P.W.U. Graefe, A.W. Chan, and M. Levi. A PRODUCTION CONTROL AID FOR MANAGERS OF MANUFACTURING PLANTS. Proceedings of the 1st International Conference on Simulation in Manufacturing, Stratford-Upon-Avon, UK. 1985

This paper discusses the shop modelling part of FAMS. The modeller can be used to simulate the running of a schedule, to validate tomorrow's schedules, to aid manufacturing managers in their response to actual machine breakdowns, and to evaluate "what-if" type situations.

4.3 D.F. Johnston. SMALL BATCH, PRECISION MANUFACTURING USING A PROTOTYPE AUTOMATED CELL. Proceedings of the 2nd International Conference, Computer-aided Production Engineering, Edinburgh, Scotland. 1987

In this paper, Johnston describes an automated manufacturing cell that is used in the dual role of being a working production system for producing real parts on a scheduled basis, and also as a prototype cell for developing new manufacturing concepts. The cell design includes using the robot for tool changing as well as parts handling and for comparison of the coordinate measuring machine parts inspection data to the original part design file. Requests for the production of finished parts, which typically are turbine blades with sculptured surfaces, are entered in the computer as standard information, and then draw on CAD parts definition, APT NC files, and manufacturing plans stored in the system. The cell uses techniques that could be applied to many job shops to provide increased productivity.

4.4 B. Van den Berg. CLOSED LOOP INSPECTION OF SCULPTURED SURFACES IN A COMPUTER INTEGRATED ENVIRONMENT. Automated Inspection and Control, Proceedings of the 8th International Conference, Chicago, IL. 1987

Van den Berg provides a detailed description of how the Coordinate Measuring Machine (CMM) in the above manufacturing cell is used for the closed loop inspection of sculptured surfaces. Alternatively, the machining centre itself, equipped with a suitable touch trigger probe, can be used to provide in-process data collection and error feedback for tolerance analysis and adaptive control.

5. CIM IN THE PLASTICS INDUSTRY

The two papers in this section, devoted to CIM in the plastics industry, are by authors from the NRC Industrial Materials Research Institute (IMRI) in Montreal.

5.1 P. Girard, G. Salloum, and P. Dion. A HIGHLY INTEGRATED ENGINEERING SOFTWARE FOR INJECTION MOLDING. A CASE STUDY. Proceedings of the 4th Canadian CAD/CAM and Robotics Conference, Toronto, Ont. 1985

This paper presents the architecture of the integrated engineering software system developed for injection molding. Among other functions, the system integrates part and mold design, flow analysis for mold filling,thermal analysis for mold cooling, mechanical analysis for mold performance prediction, and process planning for mold manufacturing.

5.2 G. Salloum, G. Laguë, P. Girard, and R. Connolly. NEW CAPABILITIES FOR THE DESIGN ANALYSIS AND OPTIMIZATION OF MOULDED PRODUCTS IN CIM ENVIRONMENTS. Proceedings of the 5th Canadian CAD/CAM and Robotics Conference, Toronto, Ont. 1986. SME Paper MS86-745

The second paper by IMRI, a complement of the previous one, focusses on the problems of mold design optimization by engineering simulation. Design optimization by process analysis and design optimization by product performance analysis based on solid modelling technology and finite element analysis are considered in turn and are advocated to be complementary.

6. FLEXIBLE MANUFACTURING CONTROL

These two papers constitute a section on flexible manufacturing control. This work was developed on the basis of the flexible manufacturing cell experimentations.

6.1 A.A. Mérabet. DYNAMIC JOB SHOP SCHEDULING: AN OPERATING SYSTEM BASED DESIGN. Flexible Manufacturing Systems: Methods and Studies. A. Kusiak (Editor). 1986. pp. 257-270

This paper describes an operating-system-based design approach to dynamic job shop scheduling for situations where the number of operations and/or the number of machines are large, or the manufacturing times are short. The implementation of this approach requires a multiprocessor multitasking operating system (such as Harmony as described in Section 7).

6.2 A.A. Mérabet. SYNCHRONIZATION OF OPERATIONS IN A FLEXIBLE MANUFACTURING CELL: THE PETRI NET APPROACH. J. Manuf. Syst. 5(3): 161-169; 1986

This second paper by Mérabet is more technical and describes a real-time shop floor controller for the flexible manufacturing cell and the

synchronization of concurrent and cooperative operations in the flexible cell by Petri nets.

7. MULTIPROCESSOR ARCHITECTURES FOR REALTIME INDUSTRIAL COMPUTING

Realtime systems have been in use since the advent of computers for process control in 1959. As a result, operating systems with special capabilities, such as the ability to handle process interrupts and to schedule multiple operations in real time have evolved to meet this need. In several papers, Gentleman describes continued development in this area. In particular, a new operating system, Harmony, which is written in C and which has new and special capabilities for multiprocessor operation, is described. These new capabilities include the capability for easy incremental growth as new processors are added to the user's system and the capability to closely synchronous tasks which run in parallel.

7.1 W.M. Gentleman. IF ONLY THE HARDWARE... (A SOFTWARE DESIGNER'S LAMENT). Proceedings of the IEEE International Workshop on Computer Systems Organization, New Orleans, LA. 1983. pp. 88-95

The first paper in this group emphasizes how the advent of portable operating systems and the availability of board level products conforming to a standard bus have reduced the hardware constraints previously imposed on software designers. This new freedom, inverting the traditional role of hardware and software, has elevated the role of operating systems, and their developers, in systems design. The first application of Harmony for work cell control in a Flexible Manufacturing System is described. Sensor-based robotics is a second and closely related application area for Harmony.

7.2 W.M. Gentleman. USING HARMONY. Canadian Information Processing Society Session '84 Proceedings, Calgary, Alta. 1984

A second paper by Gentleman presents a user's view of Harmony, described as an open, portable, operating system, implemented to run in multiprocessor configurations using the Motorola 68000 with user programs written in C. Tasks which are required to run in parallel are assigned to different processors in the multiprocessor configuration, each of which can run a number of assigned tasks (multitasking or multiprogramming) under priority control.

7.3 P.P. Tanner, S.A. MacKay, D.A. Stewart, and M. Wein. A MULTITASKING SWITCHBOARD APPROACH TO USER INTERFACE MANAGEMENT. Proceedings of the ACM SIGGRAPH '86 Conference, Dallas, TX. 1986. pp. 241-248

A third paper, by Tanner and others in the Laboratory for Intelligent Systems, concludes the three on software management for multitasking multiprocessor programming environments. Specifically, the paper concerns

Adagio, a workstation to support research in intelligent robotics which uses Harmony as its operating system, and a switchboard approach to connecting the 50 concurrent tasks which can be simultaneously active at any given time. This facilitates the implementation of windows which are included in the Adagio system for text, two-dimensional symbolic graphics, and three-dimensional views of the application such as robot simulation.

8. ROBOTICS

8.1 S. Elgazzar. EFFICIENT KINEMATIC TRANSFORMATIONS FOR THE PUMA 560 ROBOT. IEEE J. Robotics Automation, RA-1(/): 142-151; 1985

In robot manipulation and movement the transformation between the joint space and the Cartesian space of the robot is very important since robots are servoed in the joint space, whereas tasks may be defined and objects manipulated from the user point of view in the Cartesian space. A paper by Elgazzar presents an analytical study of the relationships between these two spaces and efficient kinematic transformations for the PUMA 560 robot in particular. The paper provides computationally efficient equations in closed form for the direct kinematic positions, velocities, and accelerations (i.e., given the joint angles, find the Cartesian coordinates) and their inverses. Equations are given in both general form and in numerical form using parameters for the PUMA 560 robot.

8.2 P.P. Tanner, P. Borrel, and A. Liégeois. AUTOMATIC GENERATION AND REPRESENTATION OF THE WORK AREA OF A ROBOT ARM IN A CAD/CAM SYSTEM. Proceedings of the 4th Canadian CAD/CAM and Robotics Conference, Toronto, Ont. 1985. pp. 2.5-2.8

Tanner et al. present a methodology that can be used to automatically generate and graphically portray the boundaries of each workspace that a robot can reach while maintaining a given configuration or posture. Knowledge of these sub-workspaces and their boundaries is useful because to move between them it is required that the robot pass through a transition area while changing postures. A knowledge of these sub-workspaces, or aspects, aids in the determination of possible and impossible trajectories.

8.3 G. Roth and D. O'Hara. A HOLDSITE METHOD FOR PARTS ACQUISITION USING A LASER RANGEFINDER MOUNTED ON A ROBOT WRIST. Proceedings of the 1987 IEEE International Conference on Robotica and Automation, Raleigh, NC. 1987. pp. 1517-1523

Roth and O'Hara describe their work which has yielded an industrial robot vision and control system with the capability to scan a scene of jumbled objects, select a location by which to grip one object, and then remove it from the group or pile. No prior descriptive information is required concerning the objects, since the system uses a wrist-mounted

version of the laser range camera described in Section 9 to obtain all data required. The scanning action of the camera is controlled by motion of the robot arm with satisfactory accuracy. The paper describes in detail the spatial planning used for choosing legal holdsites by which the parallel jaw type gripper can securely grasp each object without experiencing inadvertent collisions or slippage. The methodology has been tested experimentally on a variety of parts of different types and found to work well. With some computations undertaken in parallel, which is possible with the Harmony operating system, it is expected that the goal of 10 s for the acquisition of each part can be achieved.

8.4 H.I. El-Zorkany. ROBOT PROGRAMMING. INFOR, 23(4): 430-446; 1985

While today most industrial robots in service are programmed by the manually guided "teach" method, the use of off-line and language-based programming methods is expected to increase due to the cost of the equipment down time experienced during the teaching process, and as applications become more complex.

El-Zorkany presents a review of robot programming methods. These involve special considerations associated with five main issues: sensing, world modelling, motion specification, flow of control, and programming support. It is recognized that in the future, when robots are "told" where to go rather than being "shown" where to go, it will be necessary for robots to be accurate as well as repeatable.

8.5 H.I. El-Zorkany, R. Liscano, B. Tondu, and G. Sawatsky. SENSOR-BASED LOCATION AND TRAJECTORY SPECIFICATION AND CORRECTION IN ROBOT PROGRAMMING. Proceedings of the 16th International Symposium on Industrial Robot Technology, Brussels, Belgium. 1986. pp. 643-655

Accordingly, a second paper by El-Zorkany et al. is devoted to experimental work using an optical sensor and a hand-held target to generate desired task location points for a PUMA 560 robot. Alternatively, data from a CAD database can be employed. The same sensor, mounted on the robot, is then employed during robot motion to obtain actual position points as they occur. Differences are recognized between actual and desired location, and these differences can then be used to generate correctional signals in a feedback mode. This concept is then extended to trajectory specification and control with improved results in each case. Results are limited primarily by the sensor resolution and accuracy rather than by the open-loop servo system and mechanical rigidity of the robot.

8.6 X. Zhou and H.I. El-Zorkany. AUTOMATIC LOCATION DETERMINATION USING SIMPLE TOUCH SENSING. Sensors '85 Proceedings, Detroit, MI. 1986. pp. 1-12

In robot applications programmed by "showing" it is necessary for all objects to be very precisely pre-positioned in order that they may be

grasped. However, in many instances this is difficult to maintain and guarantee. An improvement in system flexibility can therefore result if only the approximate location of an object is required initially, while its actual location and orientation are later determined by means of a touch probe mounted on the robot. The mathematical transformations required to so determine an object reference frame from touch probe data are described in a third paper by Zhou and El-Zorkany, together with experimental results for repeatability and accuracy using a PUMA 560 robot.

8.7 J. Domey and N. Burtnyk. 3D VISION FOR ROBOTICS AND AUTOMATION. Proceedings of the Canadian Engineering Centennial Convention, Montreal, P.Q. 1987

A paper by Domey and Burtnyk provides a bridge between those in this group on robotics and those in the following section on computer or robotic vision. The paper explains that industrial applications of machine vision have been successful and have become well established in 2-D situations with sufficiently constrained targets, but that for 3-D situations the problems are much more complex. Range measuring cameras developed at NRC using structured laser light techniques for direct 3-D measurement, and their successful application, are described.

9. COMPUTER VISION

9.1 M. Rioux. LASER RANGE FINDER BASED ON SYNCHRONIZED SCANNERS. Appl Opt. 23(21): 3837-3844; 1984

The first paper, by Rioux, in the group of papers on computer vision, outlines the choices that exist in the design of 3-D range finders based on optical triangulation. By using synchronized scanners for projection of the light beam and receipt of the reflected spot onto a sensor, it is shown that unique capabilities can be achieved. These include the use of high-speed linear position sensors for rapid scanning, a small angular separation between projection and detection which leads to a small physical size for the camera, minimum shadow effects, and increased resolution in range without sacrificing the field of view. A prototype is described which typically can scan an object, providing 3-D range data with spatial resolutions along the X, Y, and Z axes of 1, 2, and 0.4 mm, in less than 1 s.

9.2 M. Rioux and F. Blais. COMPACT THREE-DIMENSIONAL CAMERA FOR ROBOTIC APPLICATIONS. J. Opt. Soc. Am. A, 3(9): 1518-1621; 1986

While the above range camera uses analog sensors for speed and accuracy, a second compact range sensor is described in this paper by Rioux and Blais. This utilizes a novel concept with no moving parts and a commercial camera using conventional CCD detectors. In one form of this concept the scene and object surfaces to be detected are illuminated with pinpoints of light. For an object in focus (according to the lens setting) these would

appear as points. For an object closer to the camera they will be out of focus and appear as circles whose diameter is a measure of range. Measurement of the circle diameters on the CCD detector is aided by a mask located either in front of the lens or within the aperture. The light weight and simplicity of this concept makes this camera suitable for mounting on a robot arm for guidance in grasping and assembly applications.

9.3 P. Boulanger, K.B. Evans, M. Rioux, and L. Ruhlmann. INTERFACE BETWEEN A 3-D LASER SCANNER AND A CAD/CAM SYSTEM. Proceedings of the 5th Canadian CAD/CAM and Robotics Conference, Toronto, Ont. 1986. pp. 731-737

Use of the 3-D laser scanner is further described in this paper by Boulanger et al. Essentially it has the potential to be used as a low-cost 3-D camera to create CAD databases of real objects. Possible applications exist in medicine (e.g., prosthesis) and industry (e.g., machining faithful copies of objects, including live objects such as a human face or museum artifacts). An interactive graphics system, linked to the scanner for editing and rendering the large arrays of range data from the camera, permits the use of conventional wire frame representations and is also described.

9.4 T. Kasvand, R. Oka, M. Dhome, and M. Rioux. SEGMENTATION, LEARNING, AND RECOGNITION OF OBJECTS IN RANGE CAMERA IMAGES. Proceedings of the 4th Canadian CAD/CAM and Robotics Conference, Toronto, Ont. 1985. pp. 9.17-9.27

The three or four papers above describe prototypes of successful range measuring cameras that provide elevation data, above a reference ground plane, for each point or pixel in the scene. Kasvand et al., in their paper, show that the computational procedures required for scene analysis and object recognition are far from trivial, although humans accomplish this with ease. Two methods are described for obtaining object descriptions, one from CAD models and a new method, simpler than many, in which the descriptions are learned from being "shown" the objects themselves. Experimental results show successful recognition of objects in a scene using either method.

9.5 H.F.L. Pinkney and C.I. Perratt. A FLEXIBLE MACHINE VISION GUIDANCE SYSTEM FOR 3-DIMENSIONAL CONTROL TASKS. Proceedings of the International Society for Photogrammetry and Remote Sensing, Commission V Symposium, Real-time Photogrammetry - A New Challenge, Ottawa, Ont. 1986

In an application paper by Pinkney and Perratt, working versions of machine vision guidance systems are described which are in use in both space and industrial applications. The objective in these instances is not "what is it," but rather "where is it." Vision camera data of a special

target fixed to the object are obtained at 30 Hz and processed by the applications packages at a minimum of 10 Hz to provide filtered realtime data of object position and orientation. For the space application, employed in conjunction with the Shuttle Remote Manipulator Arm, graphic displays of object position data are provided for "man in the loop" control. For the industrial application, direct output to the robot controller permits a robot to unload parts from a monorail carrier in an automotive factory. An extended Space Vision System for testing during the next Canadian Astronaut shuttle flight is also described.

9.6 M. Rioux, P. Boulanger, and T. Kasvand. SEGMENTATION OF RANGE IMAGES USING SINE WAVE CODING AND FOURIER TRANSFORMATION. Appl. Opt. 26(2): 287-293; 1987

For many applications of 3-D range cameras it is necessary to analyze the data in some manner before it becomes meaningful. Commonly, a first step in this process is to try to identify all portions of the scene for which the data, in fact, represent the surfaces of objects. These surfaces could be planar, cylindrical, or of complex form. The process of identifying those parts of the range data which represent surfaces is called segmentation and is a first step in object recognition. One common technique in the identification of surfaces is to construct a vector for every pixel in the scene. This vector for each pixel is normal to the surface defined by the other pixels in the immediate neighbourhood (i.e., window). If this is done, for example, for all pixels originating from a plane surface, the normals will all have very similar direction values. This cluster of similar values can therefore be used to "recognize" and identify the surface.

Rioux, Boulanger, and Kasvand discuss this process in their paper and then describe a new method which involves a cyclic sine wave coding of the range data. By taking the Fourier transform of this coded data, analysis of the resulting spectral space yields a number of advantages. Since the window size using this method is auto-adaptive, there are good properties with respect to noise. In the transformed space, surfaces which were planes become dots and cylinders become lines. Clustering is shown to occur for surfaces as complex as a human face, thus aiding in recognition. Although the process is computationally intensive, and therefore time-consuming when performed digitally, the Fourier transform approach also permits an optical implementation which is proposed for segmentation in real time.

10. CAD IN BUILDING RESEARCH

10.1 D.J. Vanier. THE MERITS OF A FORMALIZED PROCEDURE (BENCHMARK) FOR EVALUATING COMPUTER-AIDED DESIGN AND DRAFTING SYSTEMS. Proceedings of the Fourth Canadian Building Congress: Learning from Experience/

Avoiding Failures, Ottawa, Ont. 1985

Vanier discusses the merits of benchmarking for the formal evaluation of CAD systems. The procedures recommended are based on actual evaluation experience for two-dimensional computer-aided design and drafting (CADD) practise in the architecture, engineering, and construction (A/E/C) industry, but could be modified slightly for use in other areas. The use of a well-defined benchmark procedure, to be demonstrated by prospective vendors on a "short-list," ensures fair comparison in minimum time for the suppliers based on real problem data and avoids possible misunderstandings leading to costly surprises for the purchaser after the CADD system is delivered. The full benchmark description and evaluation procedure are available in the companion NRC publication listed.

10.2 C.S. Strelka and D.J. Vanier. A STANDARD FOR COMPUTER-AIDED DESIGN/DRAFTING (CONSTRUCTION). Proceedings of the 10th Triennial Congress of the International Council for Building Research, Studies and Documentation, Washington, DC. 1986

Recognizing that computer technology would play an important role in the construction industry, a CSA standards group was established in the early 1980s to develop a consensus on the basic issues before adoption of CAD technology became too widespread. In this paper by Strelka and Vanier the proposed standard CSA B78.5 for the computer-aided preparation of construction drawings is presented and discussed. As a framework for CAD information, a multi-tiered "tree" type of data structure is proposed, rather than simple "layering" as developed by the CAD industry in the 1970s for the design of mechanical parts and printed circuit boards. The use of primitives, pictograms, symbols, graphics, and attributes is discussed.

10.3 K. Ruberg and D.M. Sander. INFORMATION AND KNOWLEDGE FOR BUILDING: A ROLE FOR EMERGING TECHNOLOGY. Proceedings of the 10th Triennial Congress of the International Council for Building Research, Studies and Documentation, Washington, DC. 1986

In addition to the emerging use of CAD in the building construction industry as above, Ruberg and Sander focus attention on the use and benefits of knowledge-based expert systems (KBES). During the building cycle, the successful flow of information between team members, such as user, designer, and contractor, ultimately defines the building. Poor or uninformed decisions may lead to problems. In addition, there is a widespread use of heuristic rules in the design process. Accordingly, there is considerable opportunity for KBES that can interpret, predict, diagnose, design, plan, and control. Application examples for KBES include investment planning, interpretation of user needs, project planning, building design, cost estimating, office layout, maintenance scheduling, and emergency procedures. Reference is made to a KBES under development at NRC for the design of windows. The critical need, throughout the industry, to structure previously fragmented knowledge bases is identified.

11. AI IN CAD/CAM AND CIM

11.1 F. Vernadat. OVERVIEW OF AI APPLICATIONS IN CAD/CAM. Proceedings of the 4th Canadian CAD/CAM and Robotics Conference, Toronto, Ont. 1985. pp. 9.9-9.16

With the above paper almost as an introduction, this brief section concerning applications of Artificial Intelligence (AI) in CAD/CAM and CIM, where it will be of increasing importance, logically follows. Vernadat presents an overview starting with a useful tutorial introduction to AI and expert systems. A principal difference between expert systems and conventional computer programs is that in expert systems the control structures and inference procedures are kept separate from the knowledge base. Considerable potential is seen for the use of expert systems in both CAD and CAM. Potential applications, for which some examples exist, include design to specification, process planning, and job shop scheduling.

11.2 J. Scrimgeour. EXPERT SYSTEMS - A REVIEW OF THEIR POTENTIAL AND APPLICATION IN CANADA. Proceedings of the 1986 Canadian Conference on Industrial Computer Systems, Montreal, PQ. 1986

In this paper the author seeks to place AI and expert systems in perspective in order to present a review of their potential and application in Canada. From a review of the literature, AI is seen to contain three main branches of development, (1) the understanding of the mechanisms of mental faculties and thought in which computers are used as tools, (2) the development of new improved computer applications such as expert systems, and (3) the development of systems able to respond to their environment, such as in some sensor-based computer systems, vision systems, and systems with autonomous capability. The attributes associated with most expert systems are identified. An early Canadian example, dating to 1958-59, is described for the design to specification, or design synthesis, of large synchronous motors which had many, but not all, of the attributes of current day expert systems. The paper concludes with suggestions for the development of a Canadian plan emphasizing selected application areas.

12. CONCLUSION

12.1 J. Scrimgeour. DEVELOPMENT OF THE CAD/CAM INFRASTRUCTURE IN CANADA: 1975-1985. Proceedings of the 5th Canadian CAD/CAM and Robotics Conference, Toronto, Ont. 1986. Addendum pp. 5-29

In this final paper a review is presented on the development of the CAD/CAM infrastructure in Canada over the 1975-1985 decade. Key events include the establishment of the CAD/CAM Technology Advancement Council in 1978, publication of their report "Strategy for Survival" in 1980, and establishment of approximately 75 CAD/CAM and robotic centres, widely distributed across Canada. These have been largely planned and developed by

organizations in the private sector as a response to this technology. Data are presented on the growth and penetration in industry of CAD, NC, and robotics technologies. The paper stresses the importance of technology transfer, diffusion, and the development of human resources, including strategic planning by senior management, if the Canadian manufacturing industry is to keep abreast of the technology and maintain a competitive position.

ADDITIONAL REFERENCES

The additional list of approximately one hundred references gives an overview of most of the published materials by NRC staff in the area of CAD/CAM and Robotics. Most of the references are very specific on a given problem. However, some more general papers or bibliographies have been published and are worthy of special mention. More specifically, an index and guide to CAD/CAM technology in general (Scrimgeour, 1985b), a reference guide to CAD/CAM and Robotics Development and Information Centres in Canada and USA (Canada. National Research Council, 1985), an index and guide to Robotics research in Canada (University of Toronto, 1985), Robotics bibliographies (Abdelmalek, 1981, 1982, 1983a,b), and a commented and indexed bibliography on CAD/CAM databases have been published and are available from NRC (Editorial Office, Room 301, Division of Electrical Engineering, National Research Council of Canada, Ottawa, Ontario, Canada K1A 0R8).

Finally it should be noted that this publication, for practical reasons, has not attempted to cover NRC work in related areas such as computer graphics, computer aided instruction, photogrammetry, artificial intelligence, and others.

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J. Scrimgeour
F. Vernadat

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